EUROPEAN UNION

Structural Instruments 2014-2020

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"Investing in Sustainable Development"

nuclear physics

Extreme Light Infrastructure-Nuclear Physics (ELI-NP) - Phase II

IFIN-HH

Optimization of secondary particle production from laser wakefield accelerated electrons

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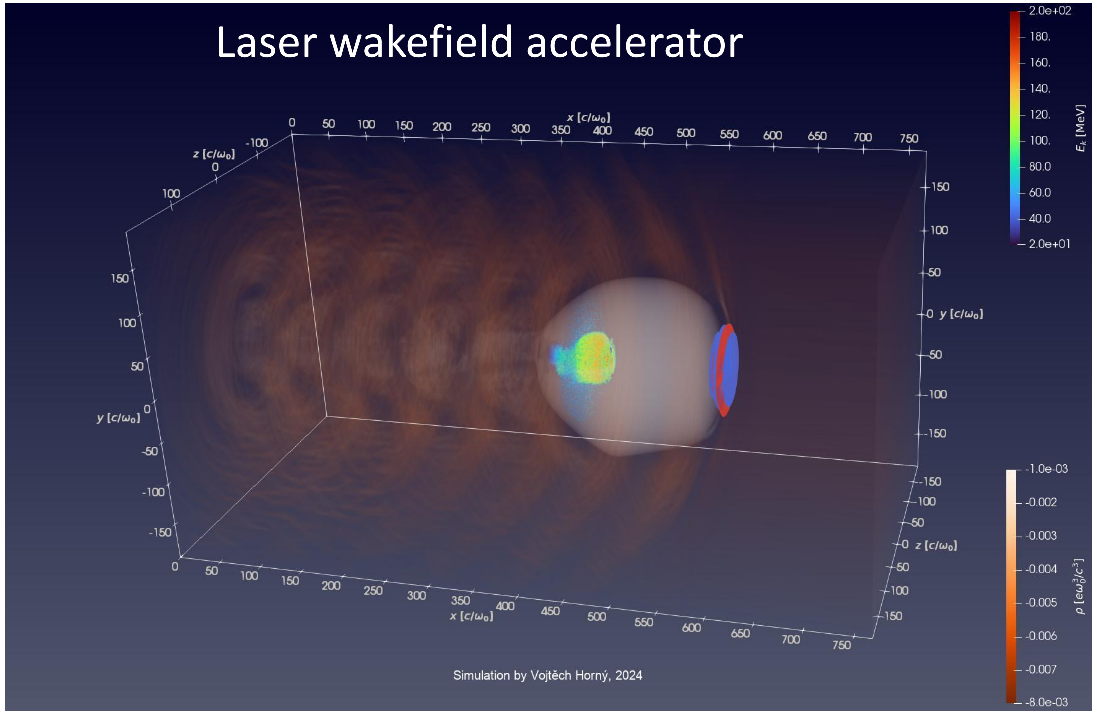
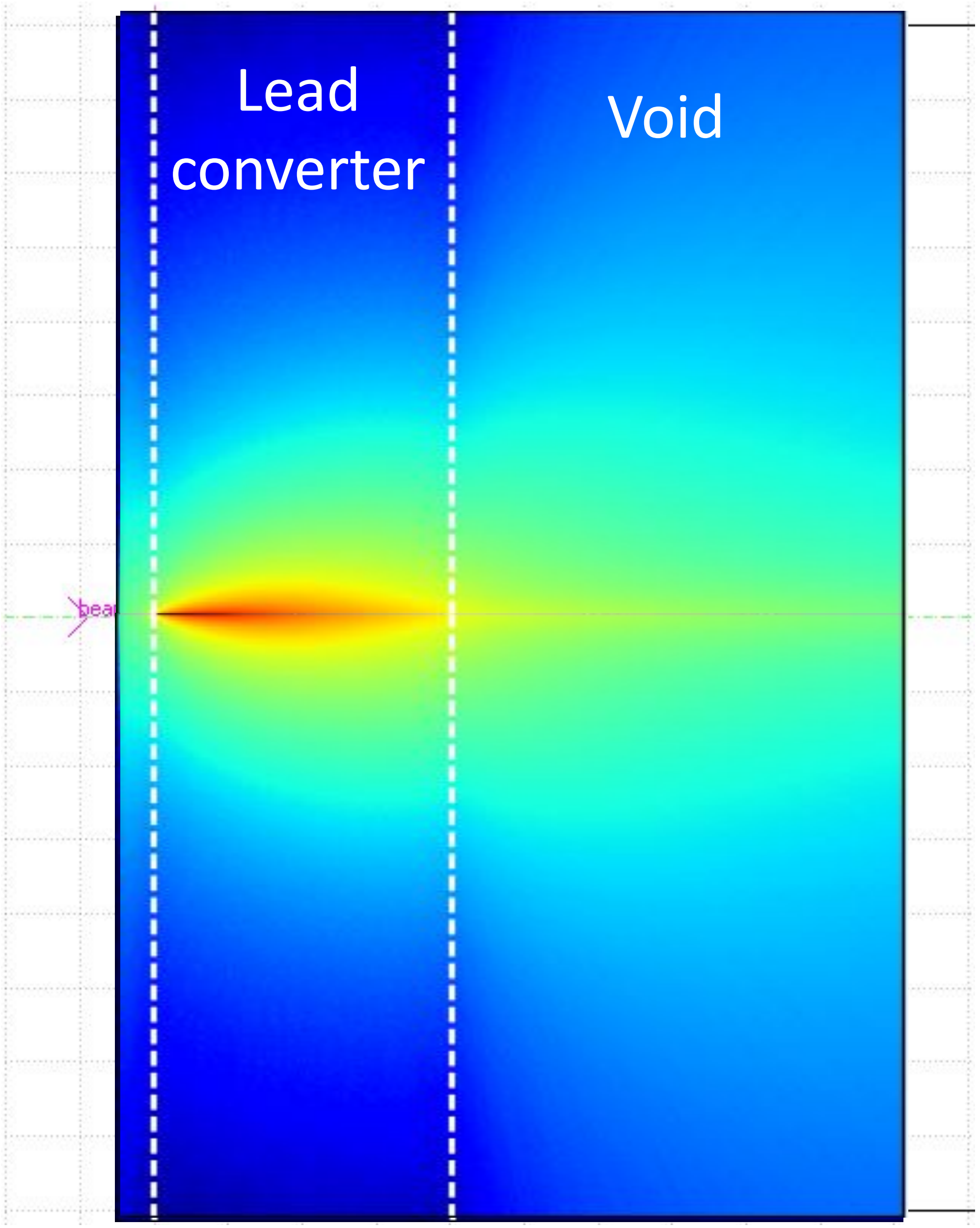


Neutrons

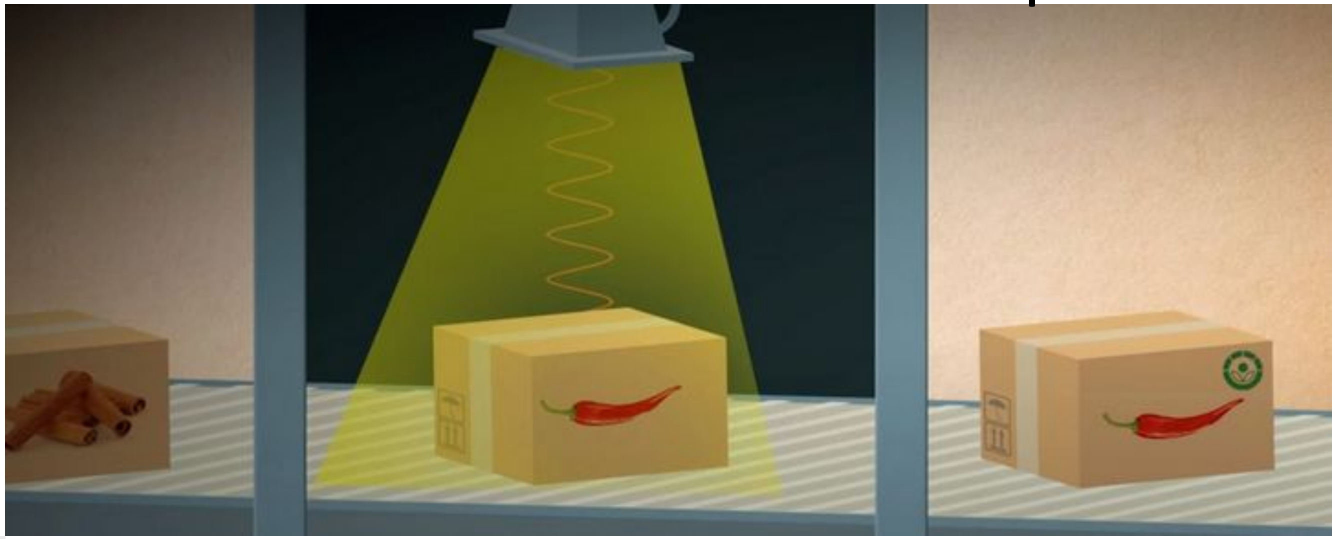


Motivation Applications of photons

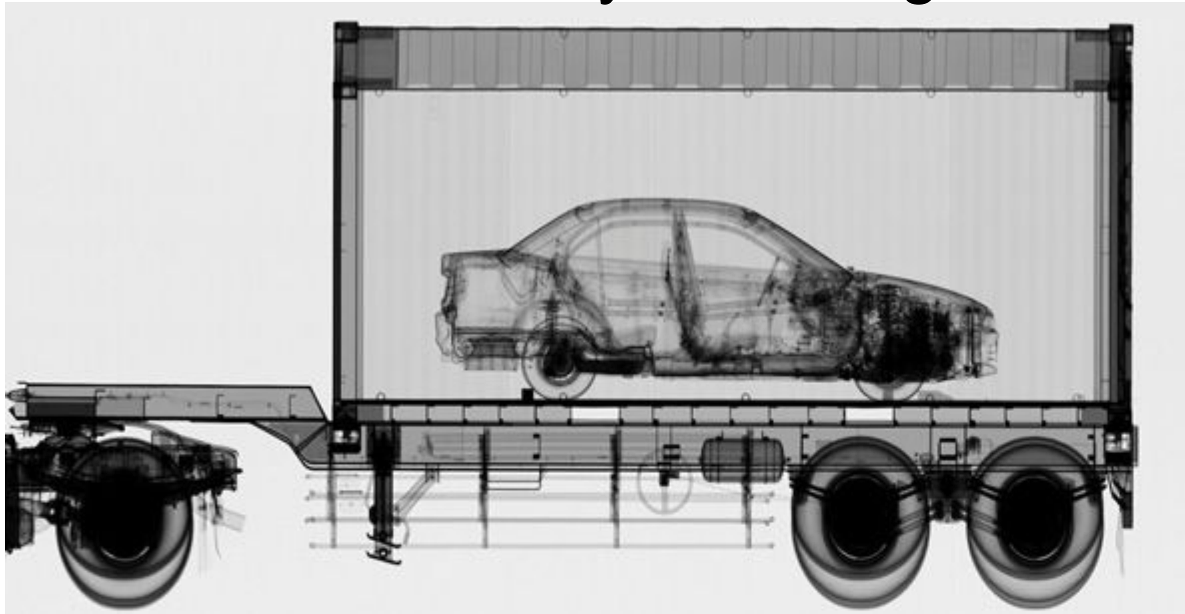
Radiotherapy

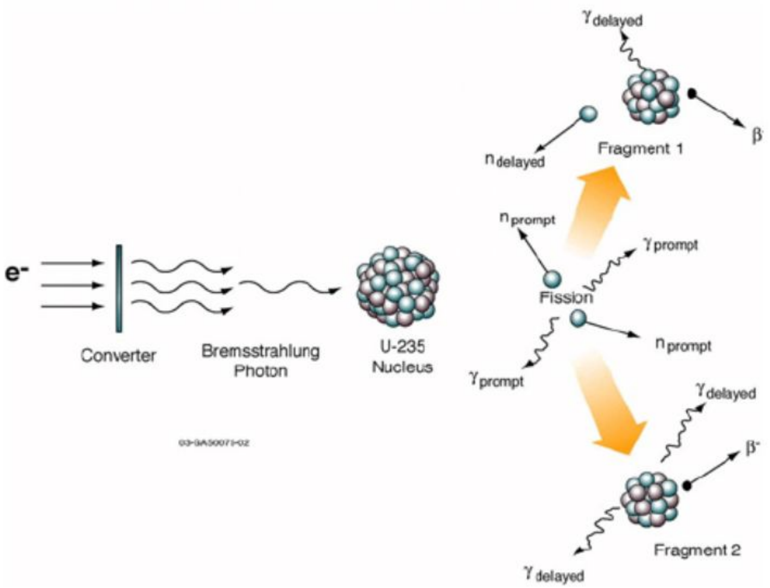
X-ray imaging

sterilization of medical and food products



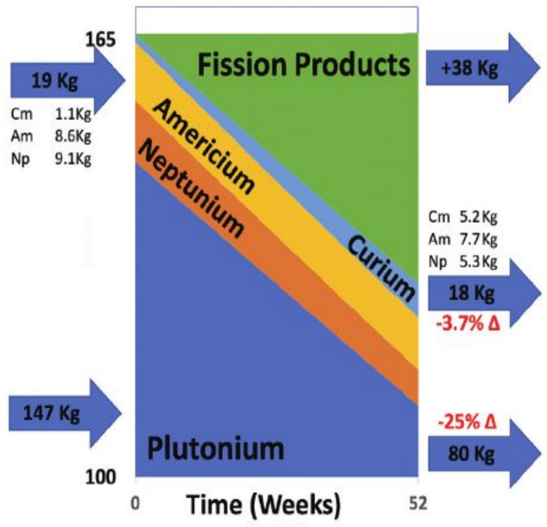
Security Scanning



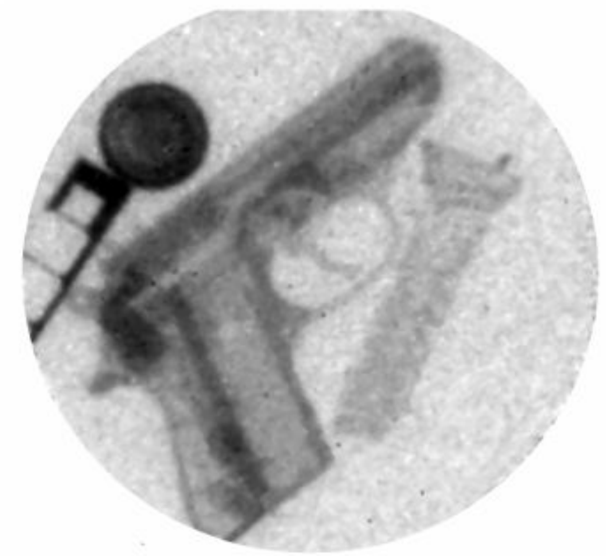


Nuclear Photofission

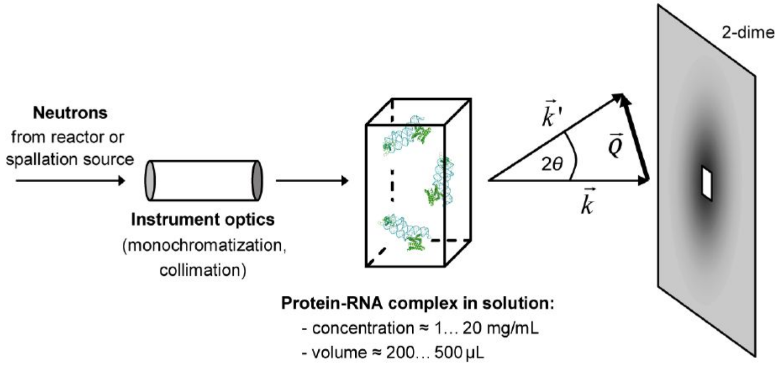
Applications of neutrons



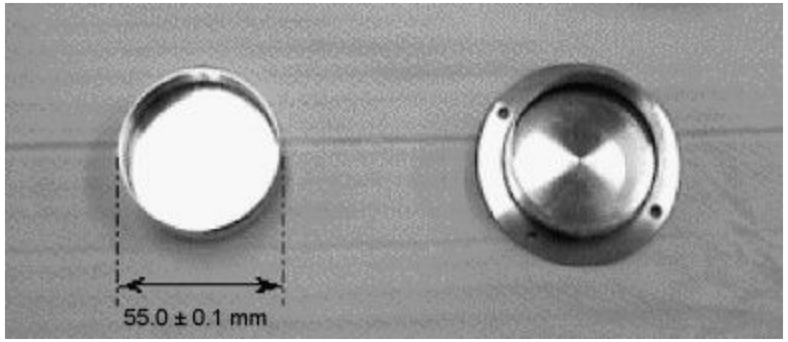
Spent nuclear fuel incineration



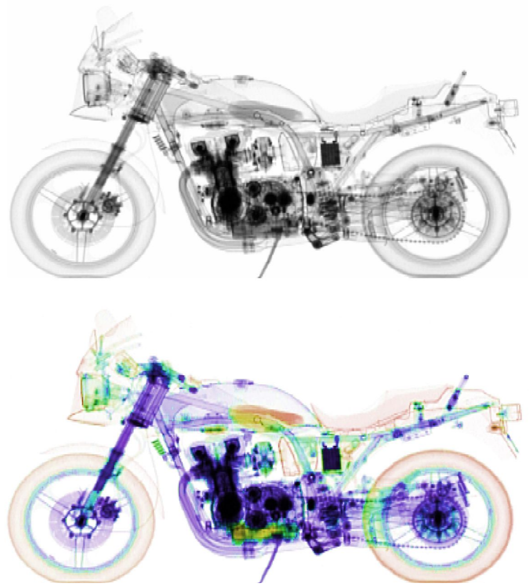
Reconstruction of material elemental composition using *fast neutron resonance radiography.*



Small-angle neutron scattering of **RNA–protein complexes**

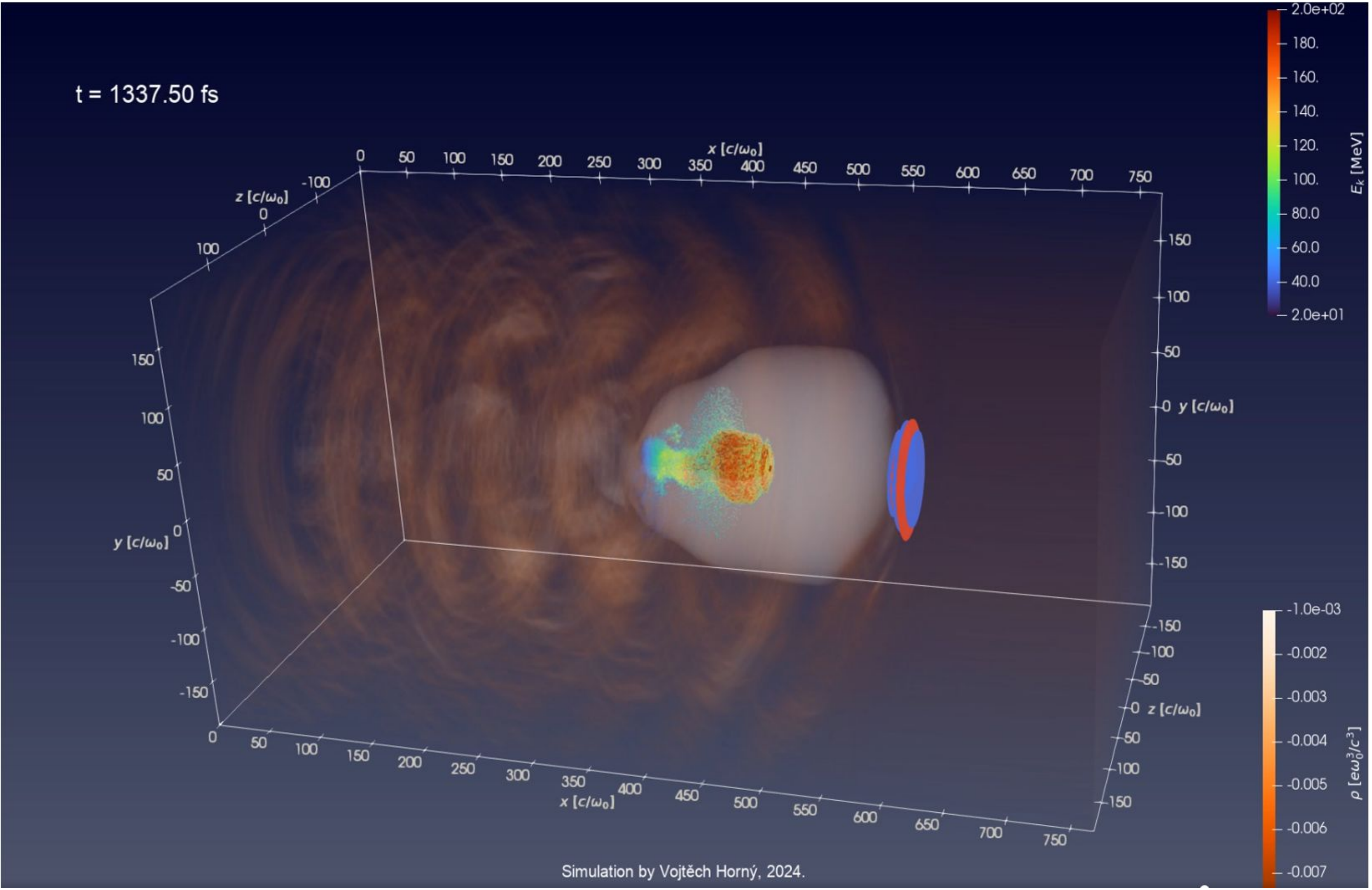


Non-destructive analysis of materials by *neutron resonance transmission*



Fast Neutron and Gamma-Ray **Interrogation of Cargo Containers**

How it works. Laser Wakefield acceleration



Laser energy: 1.5J

Laser power: 100TW

Repetition rate: 1Hz

Electron energies:
300 MeV (LWFA)
600 MeV (PWFA)

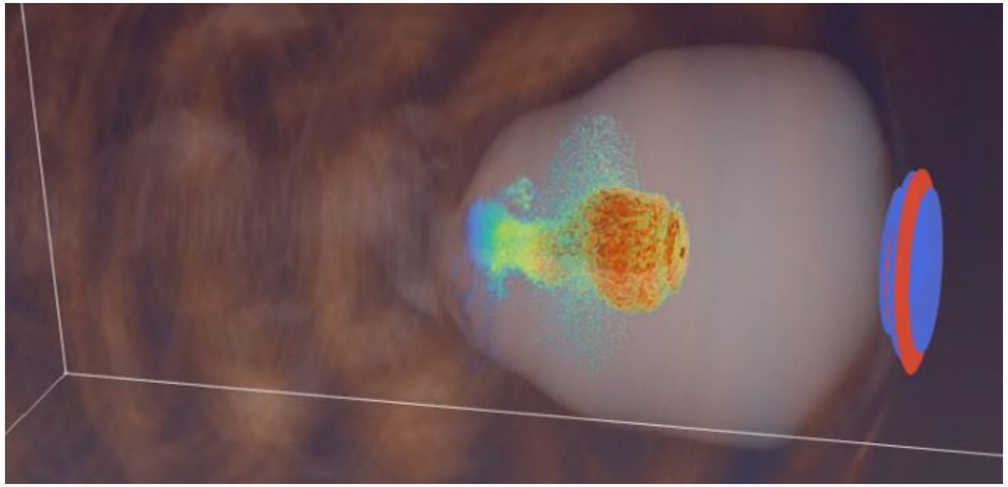
Phys. Rev. E 110, 035202

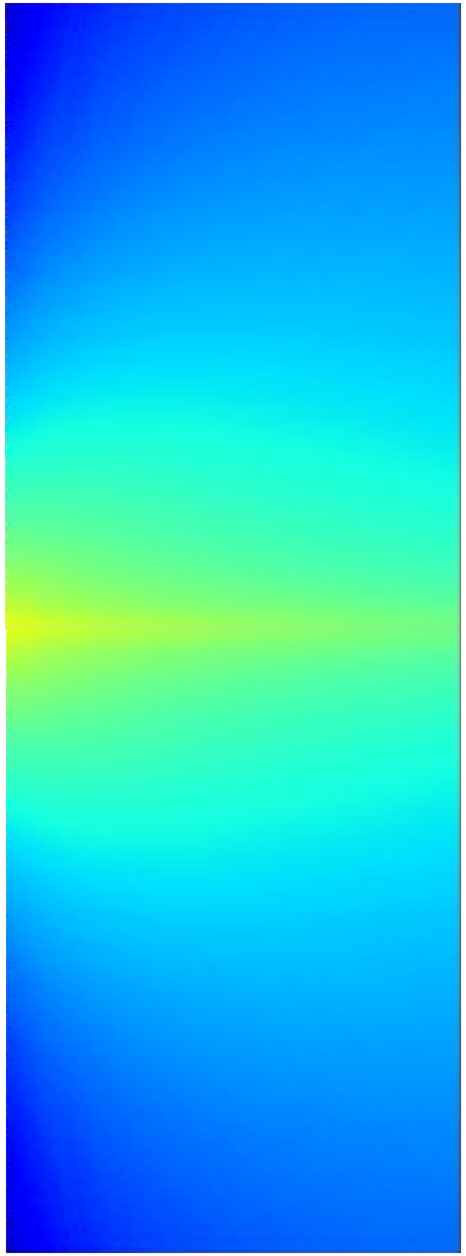
Converter

Lead

R = 8 cm

L = [0.2, …, 7] cm





Physical principle

Bremsstrahlung (breaking) radiation

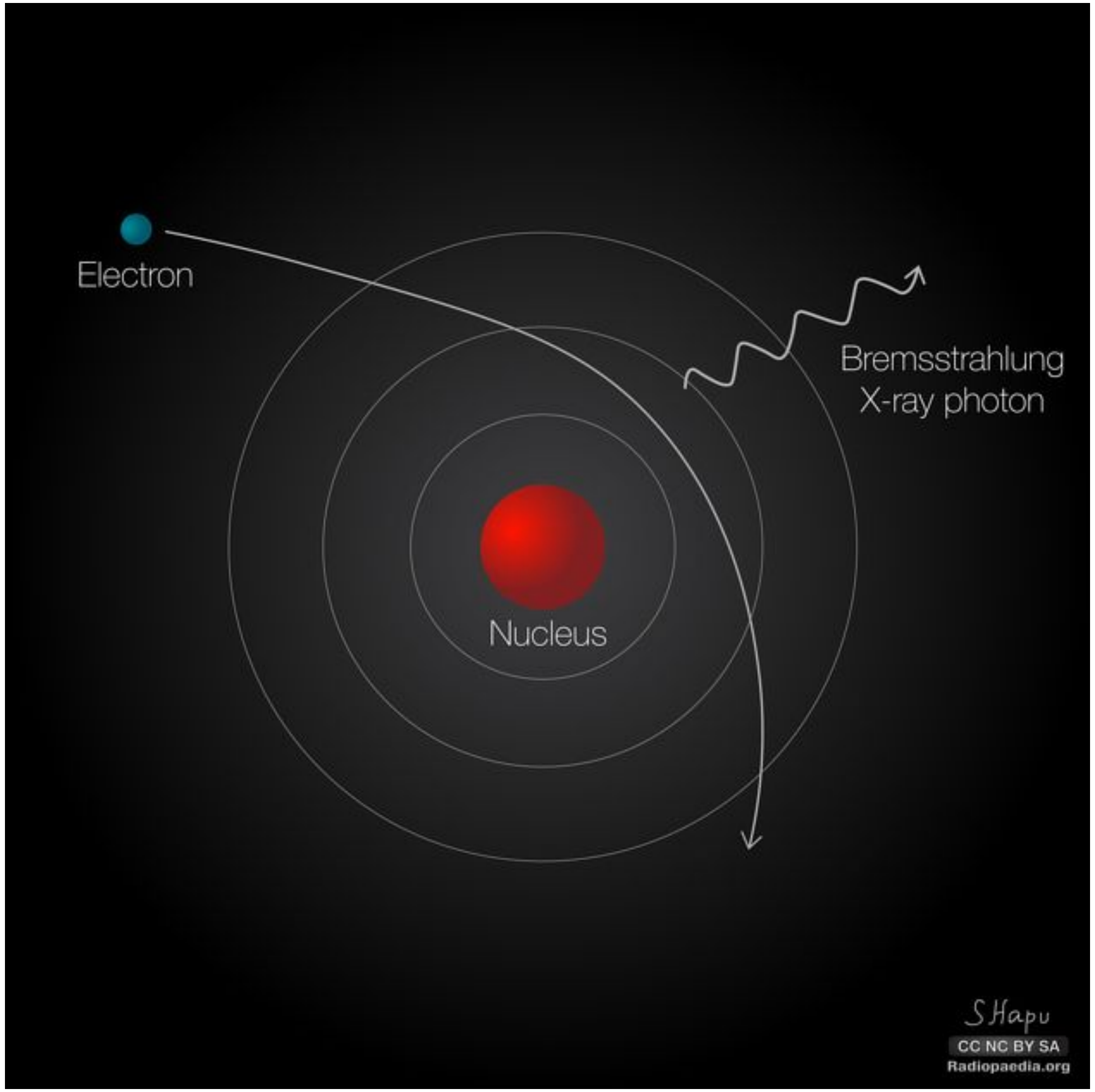
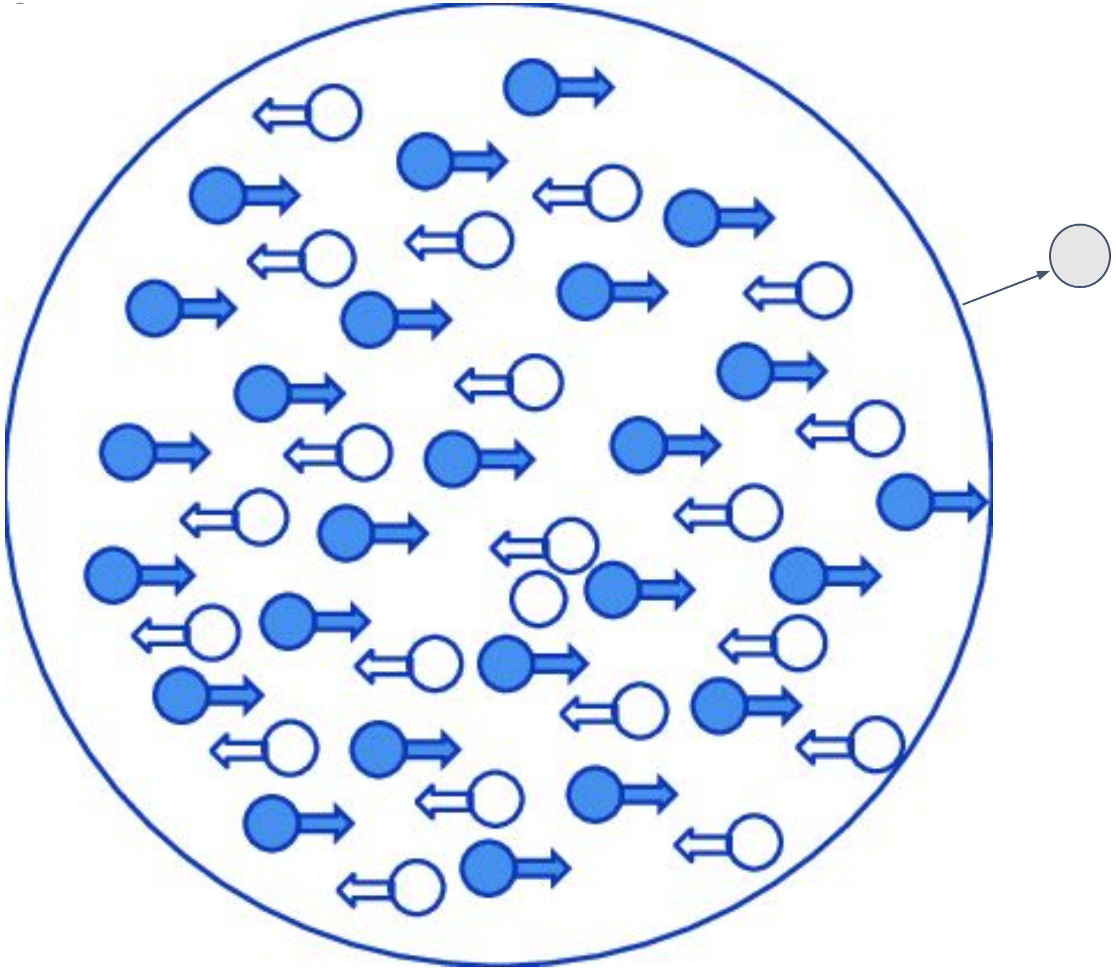
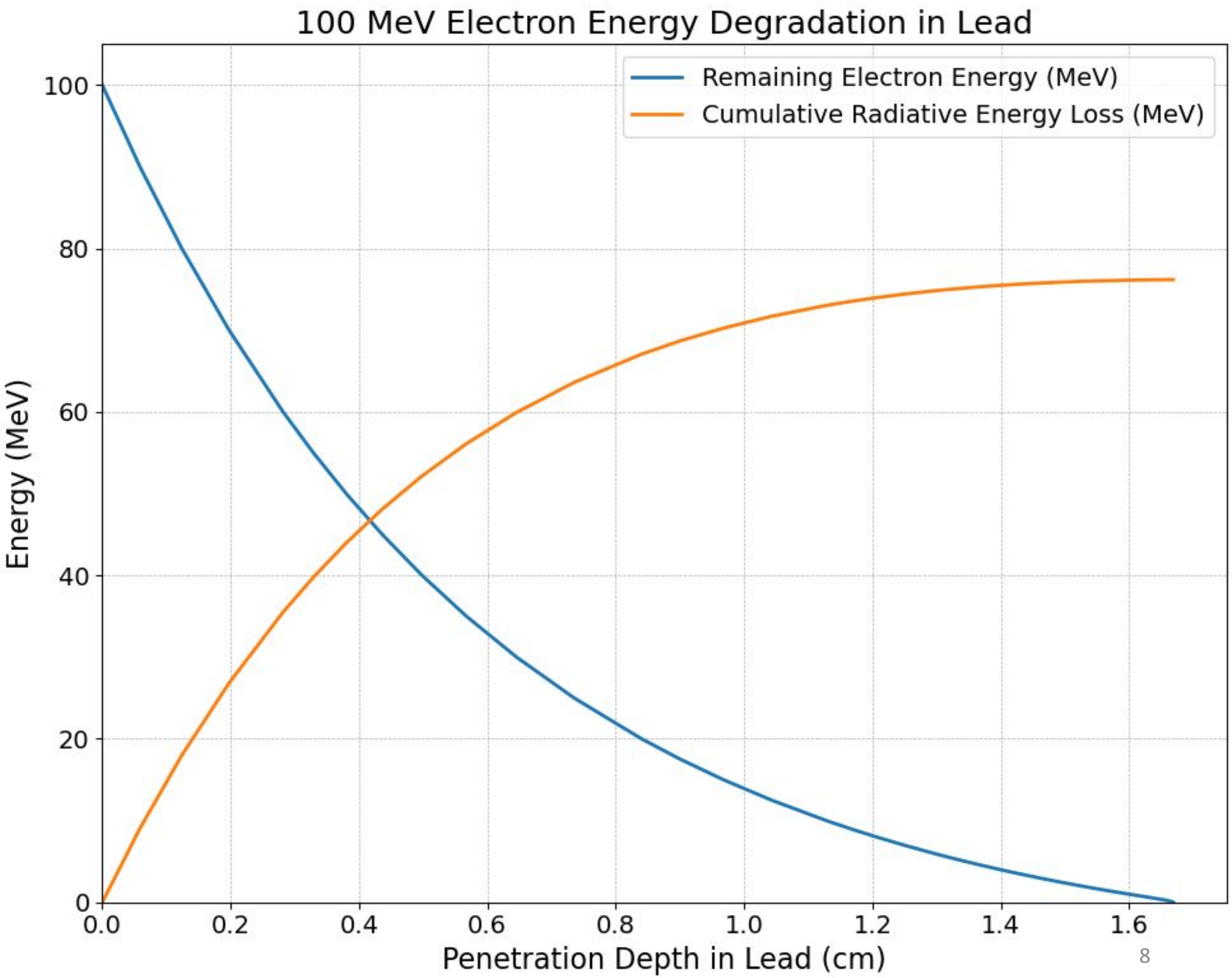
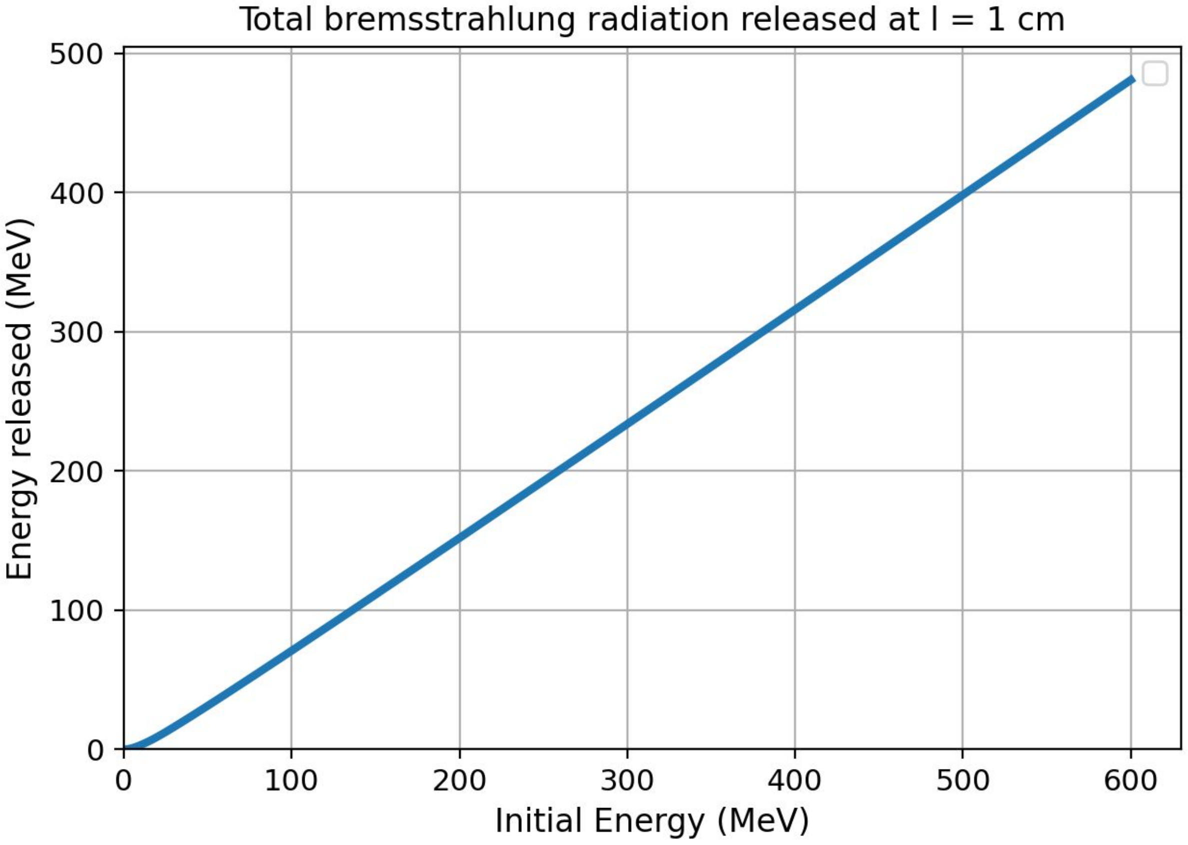


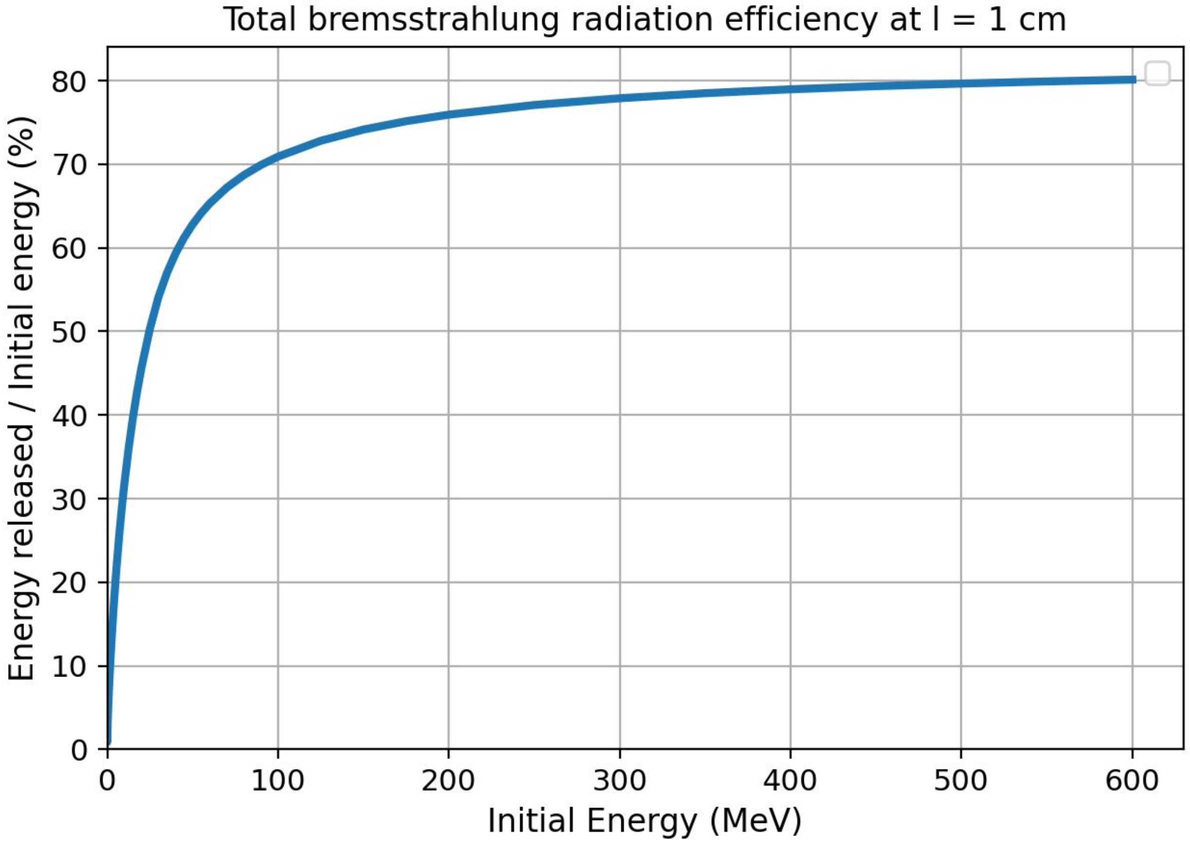
Photo-nuclear reaction via Giant Dipole Resonance.



Calculation based on Estar database stopping power data for lead







Calculation based on Estar database stopping power data for lead

Physical principle

Bremsstrahlung (breaking) radiation

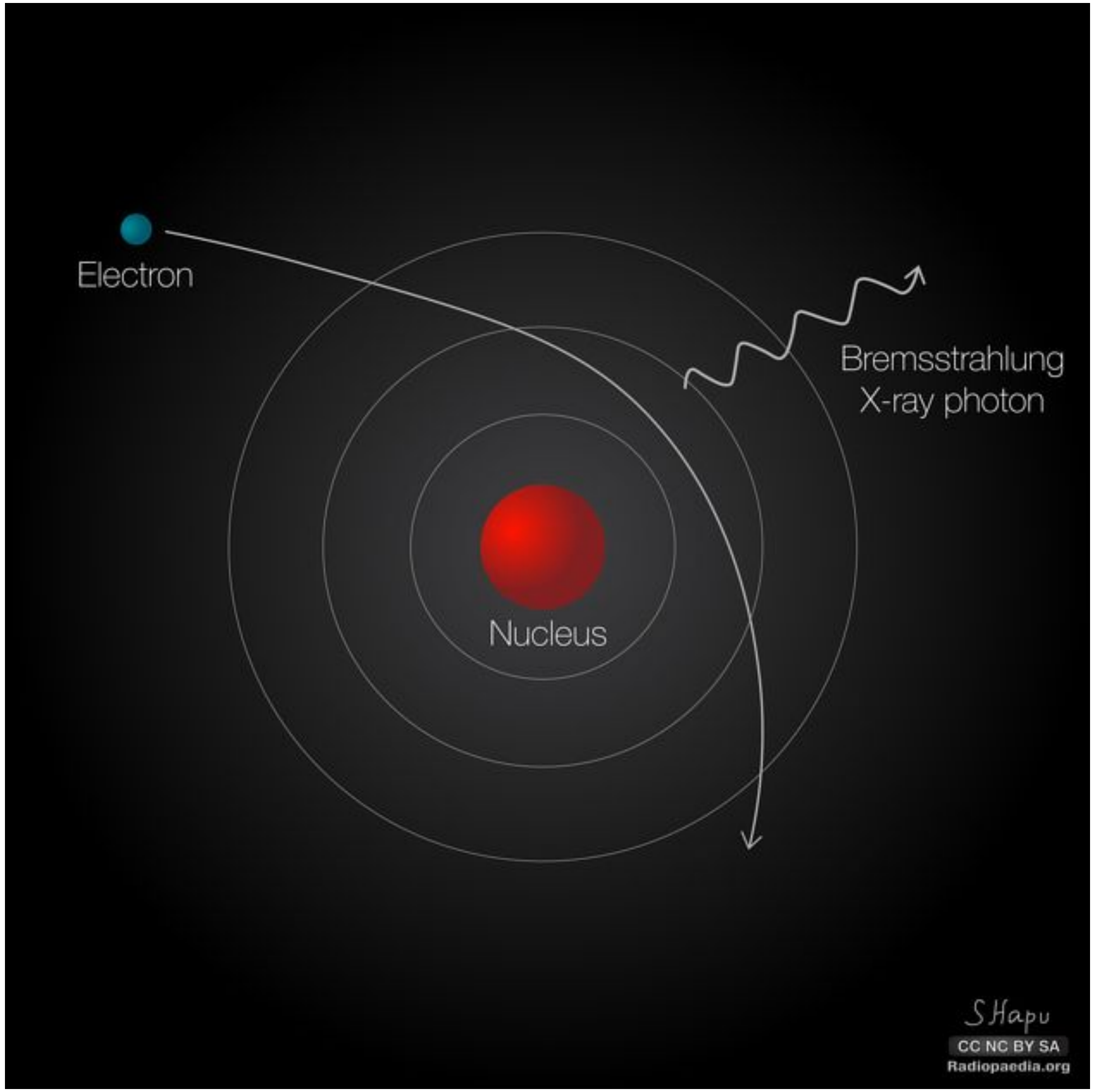


Photo-nuclear reaction via Giant Dipole Resonance.

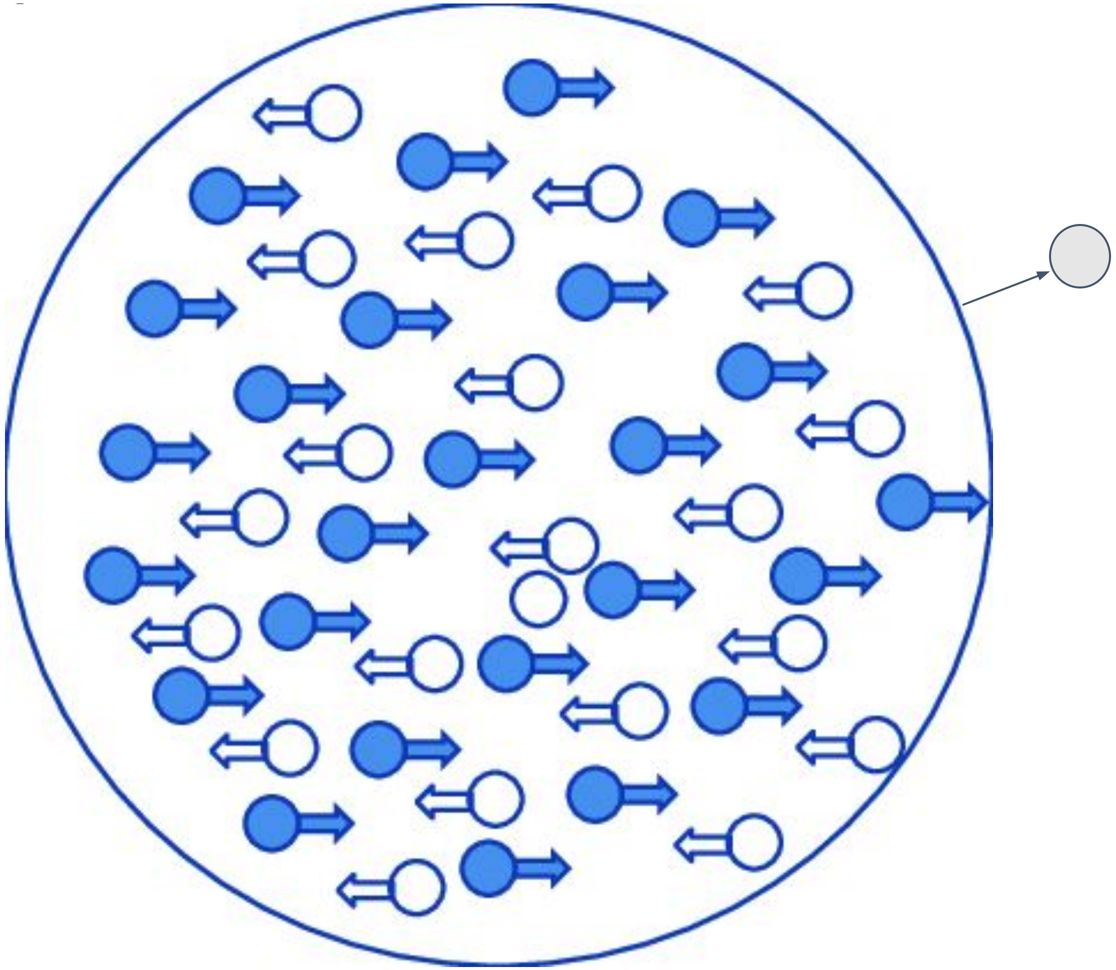
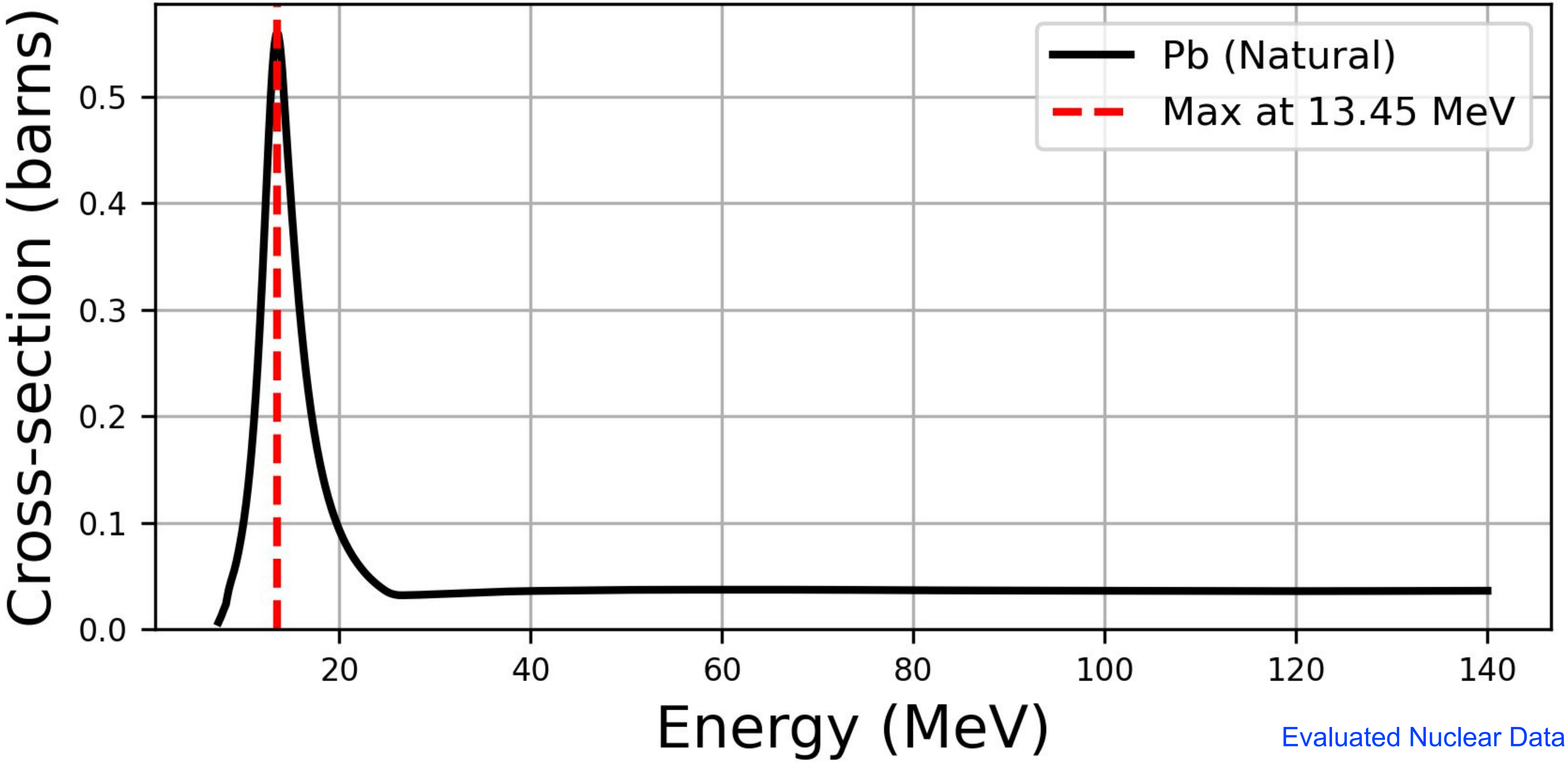


Photo-nuclear reaction cross-section



Evaluated Nuclear Data File

Methodology: *monochromatic electron source (IEB)*

```
E = [25, 50, 75, 100, 150, 250, 350, 500, 1000] MeV
ls = [0.2, 0.5, 0.75, 1, 1.5, 2, 2.6, 2.8, 3, 3.4, 3.6, 3.8, 4, 4.2, 4.4, 4.6, 4.8, 5, 5.2, 5.4, 6, 7, 8]   cm
```

Ideal Electron Beam (E)

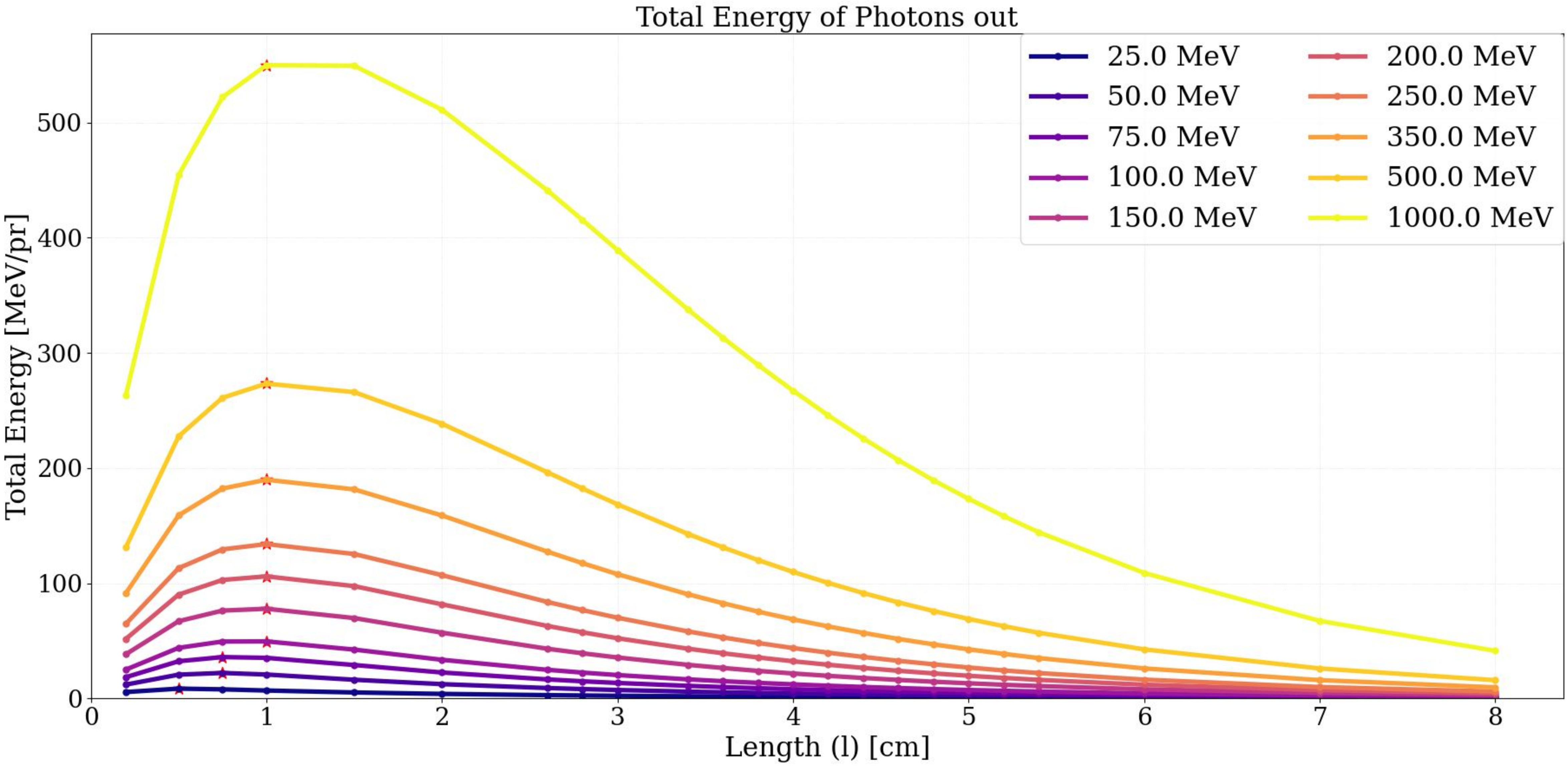
length

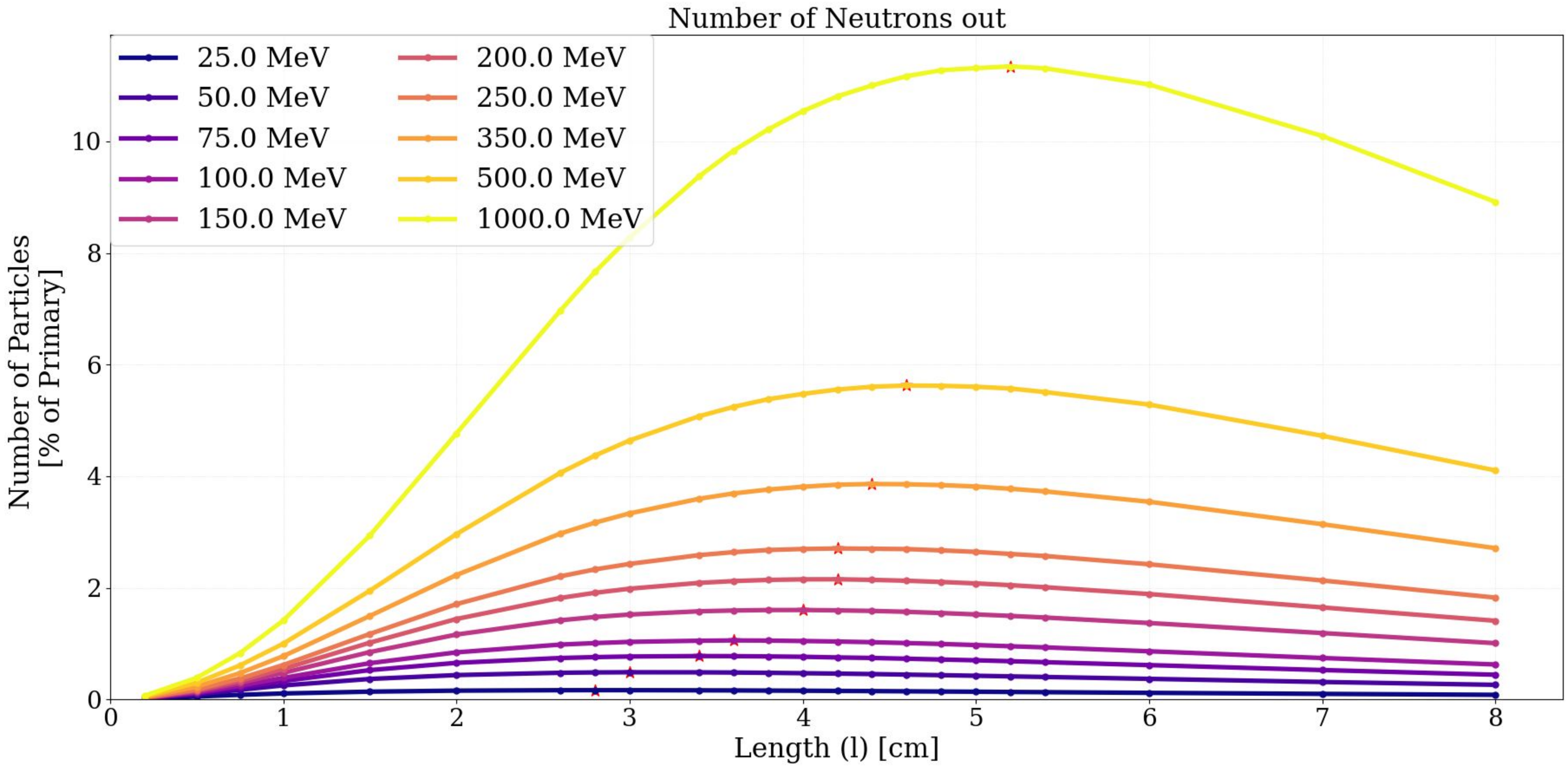
FLUKA

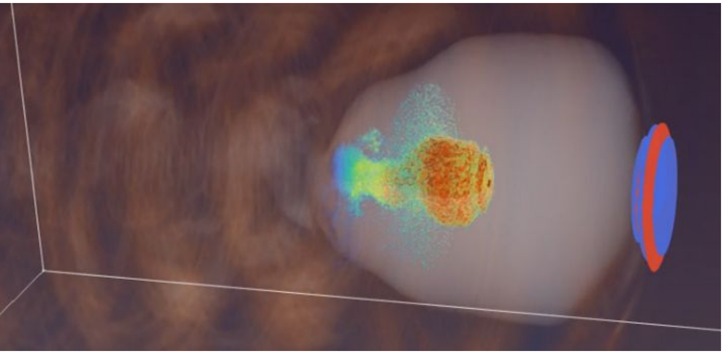
Spectra of particles (neutrons, photons, electrons, positrons, muon, antimuon.) + area density

- Total number of neutrons
- Total energy of photons
  - Optimal length

Results:

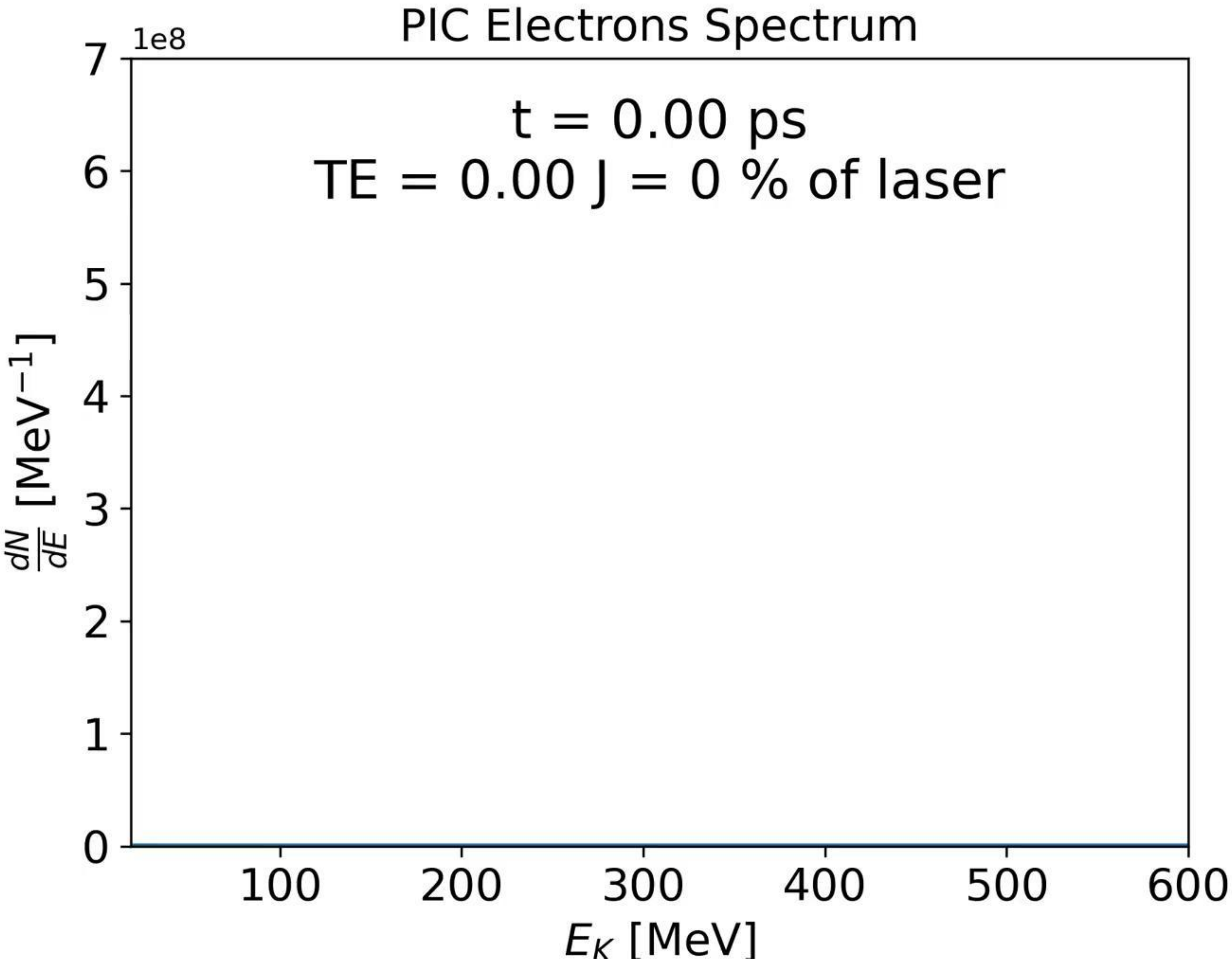

Total Energy of Photons out
25.0 MeV
50.0 MeV
75.0 MeV
100.0 MeV
150.0 MeV
200.0 MeV
250.0 MeV
350.0 MeV
500.0 MeV
1000.0 MeV
Total Energy [MeV/pr]
Length (l) [cm]
0
100
200
300
400
500
0
1
2
3
4
5
6
7
8

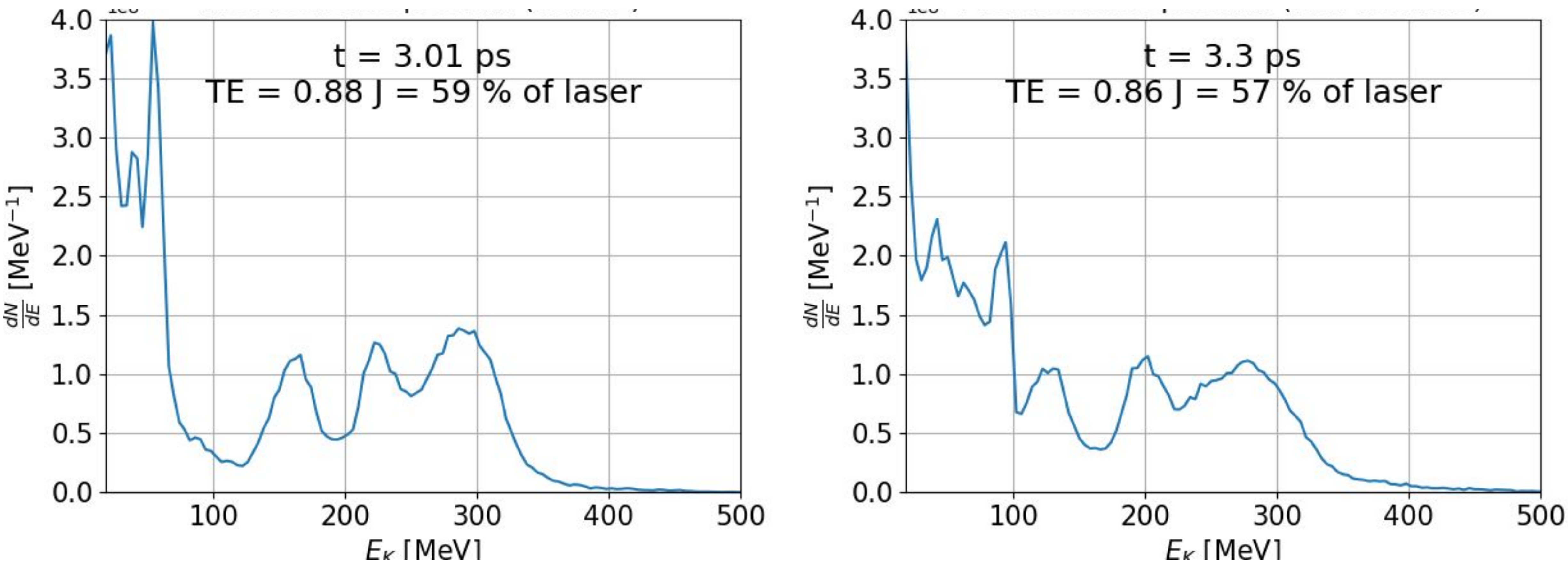

Number of Neutrons out
25.0 MeV
50.0 MeV
75.0 MeV
100.0 MeV
150.0 MeV
200.0 MeV
250.0 MeV
350.0 MeV
500.0 MeV
1000.0 MeV
Number of Particles [% of Primary]
Length (l) [cm]
0
2
4
6
8
10
0
1
2
3
4
5
6
7
8



Laser energy: 1.5 J
Laser power: 100 TW
Repetition rate: 1 Hz

λ = 0.82 μm
w_0 = 10 μm
a_0 = 8.57
n_0= 6.84e18 cm^{-3}




t = 3.01 ps
TE = 0.88 J = 59 % of laser
$\frac{dN}{dE}$ [MeV^{-1}]
E_K [MeV]
t = 3.3 ps
TE = 0.86 J = 57 % of laser
$\frac{dN}{dE}$ [MeV^{-1}]
E_K [MeV]

Methodology electron spectra from PIC simulatoms

```
ts = [0.5, 1, 1.5, 2, 2.5, 2.7, 2.8, 2.9, 3, 3.05, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.9, 4, 4.1, 4.3, 4.6, 5, 5.5, 6] ps
ls = [0.2, 0.5, 0.7, 0.8, 0.9, 1, 1.1, 1.2, 1.3, 2, 2.5, 3, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.5, 5, 6, 7] cm
```

Electron spectrum (t)

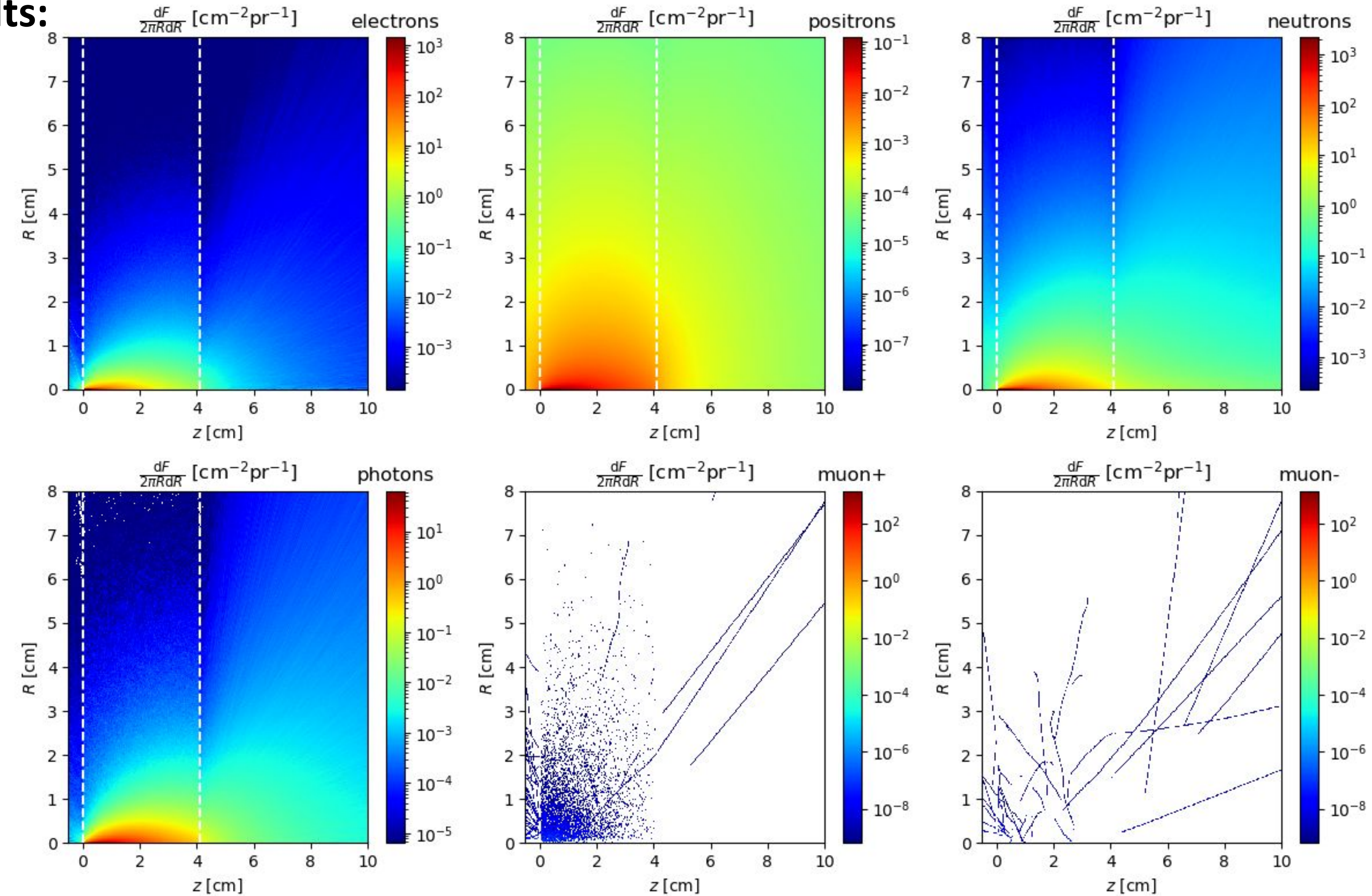
length

FLUKA

Spectra of particles (neutrons, photons, electrons, positrons, muon, antimuon.) + area density

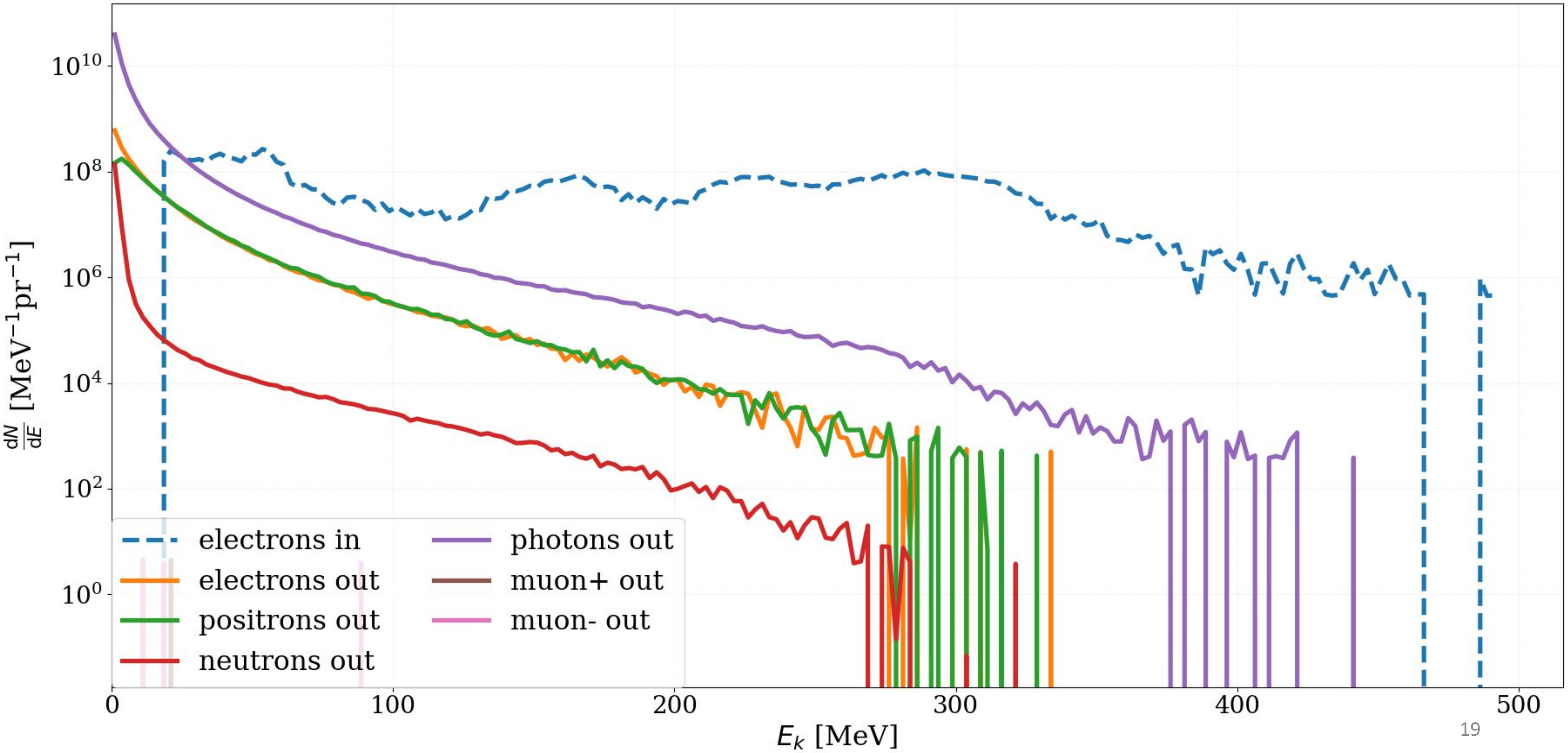
- Total number of neutrons
- Total energy of photons
  - Optimal length

Results:

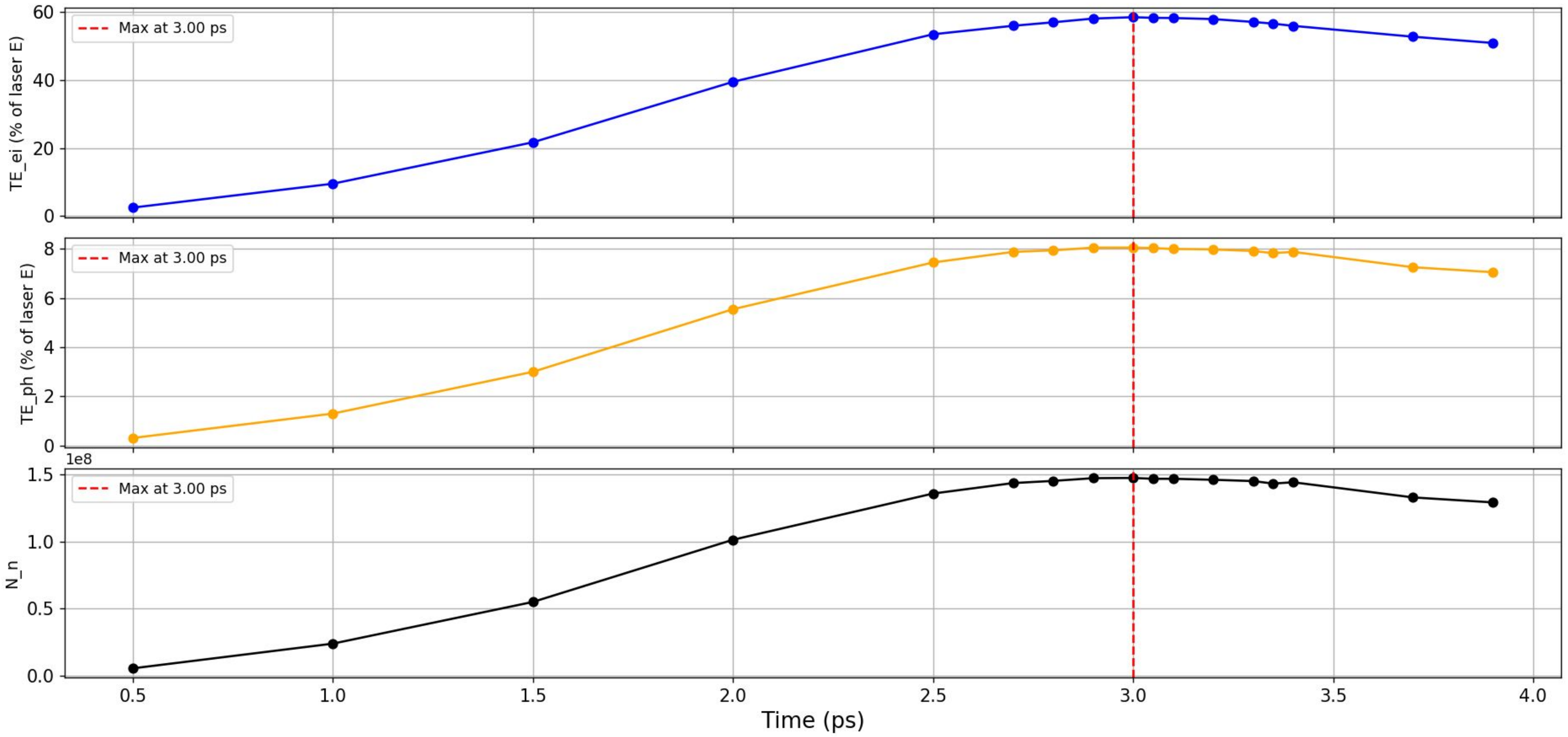


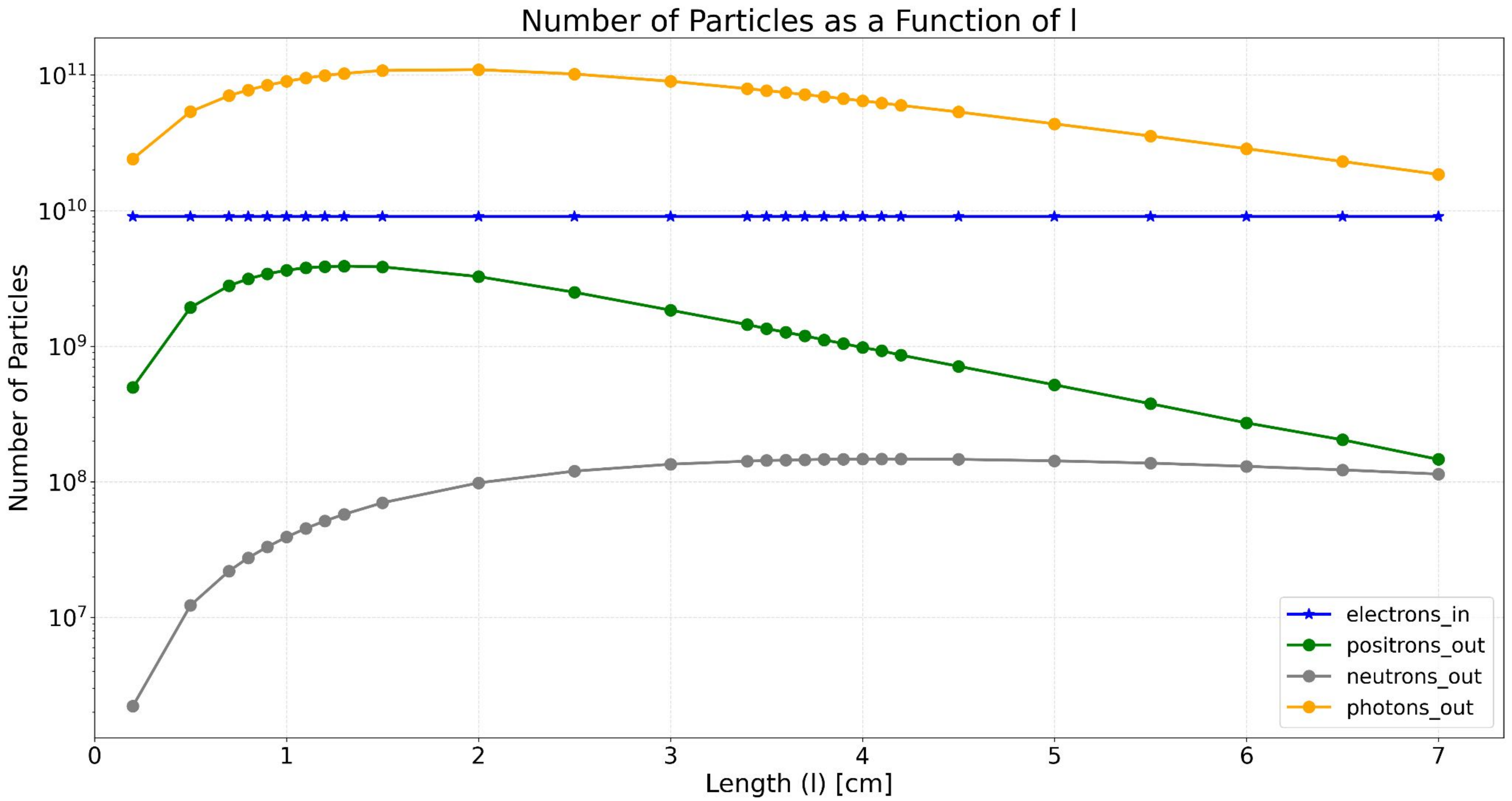
$\frac{dF}{2\pi R dR}$ [cm^{-2}pr^{-1}]
electrons
positrons
neutrons
photons
muon+
muon-
R [cm]
z [cm]

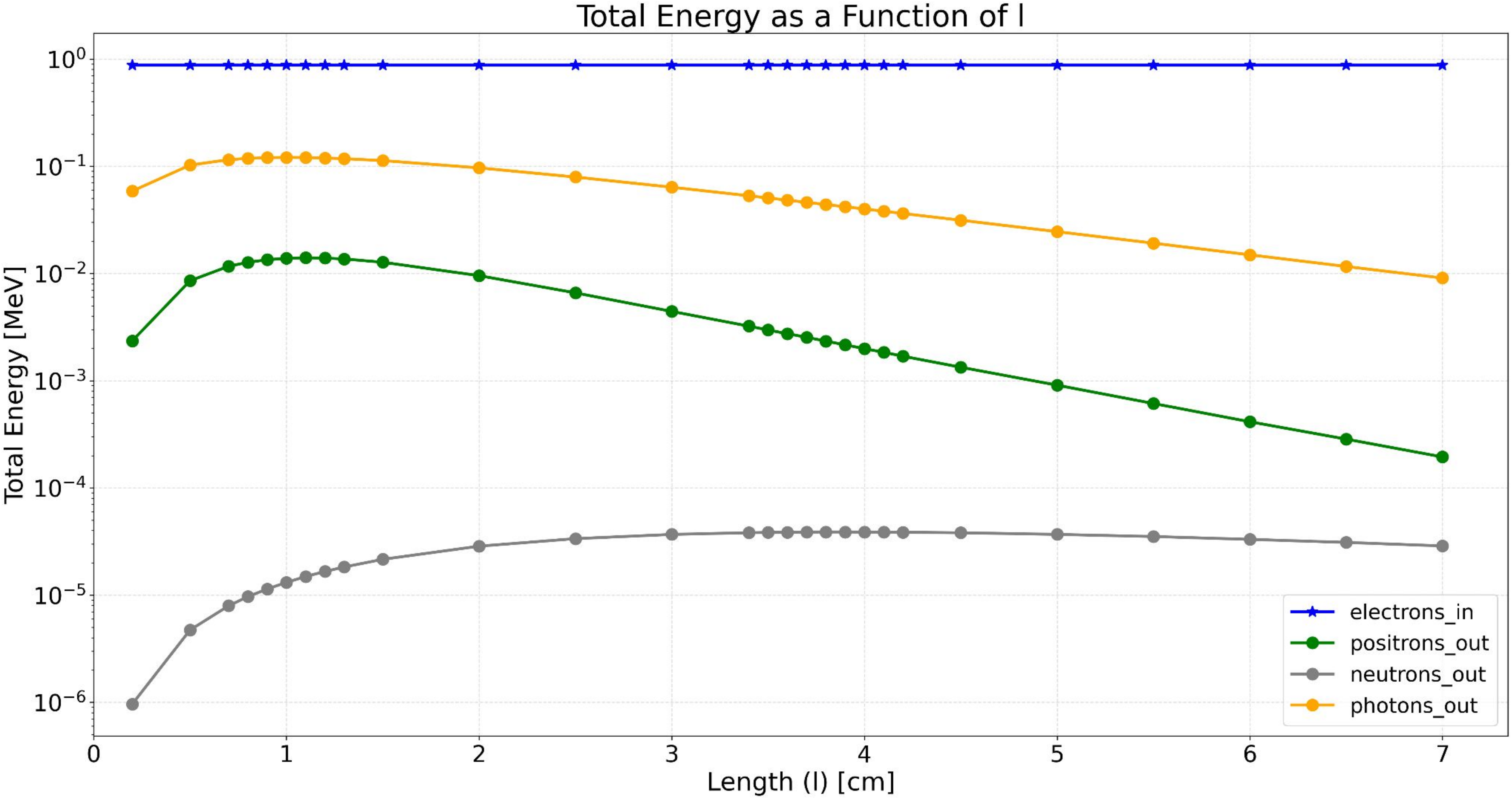
Particles spectra from PIC; time in PIC = 3.0ps; converter length = 4.1cm



Results of simulations (PIC electrons)




Number of Particles as a Function of l
Number of Particles
Length (l) [cm]
electrons_in
positrons_out
neutrons_out
photons_out
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
0
1
2
3
4
5
6
7



Total Energy as a Function of l
Total Energy [MeV]
Length (l) [cm]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
1
2
3
4
5
6
7
electrons_in
positrons_out
neutrons_out
photons_out

Conclusion

For this laser-plasma configuration, optimal time for both photon energy and neutron production is **3.0 ps**, which corresponds to the maximum total energy of electrons.

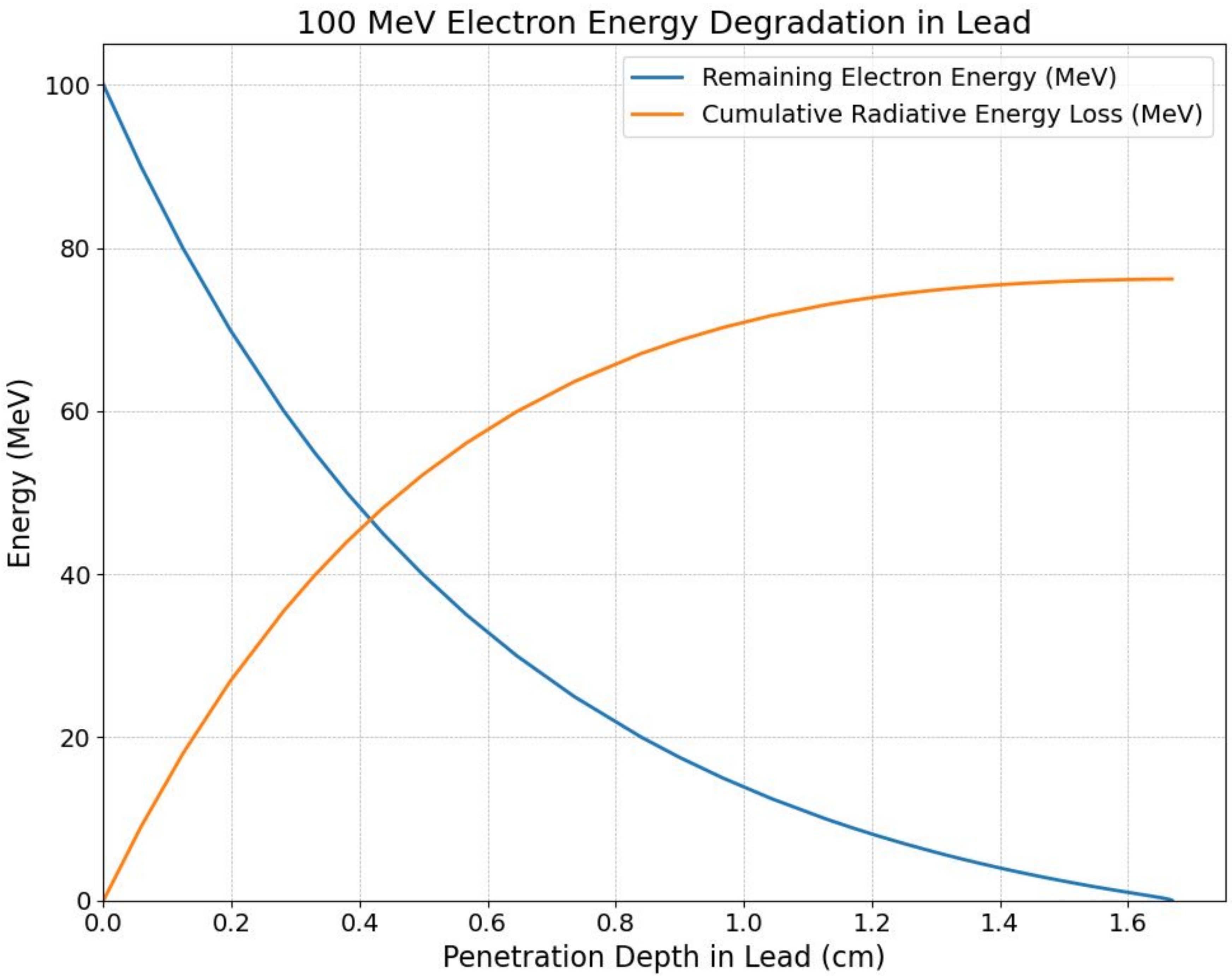
Length of the converter to maximize the

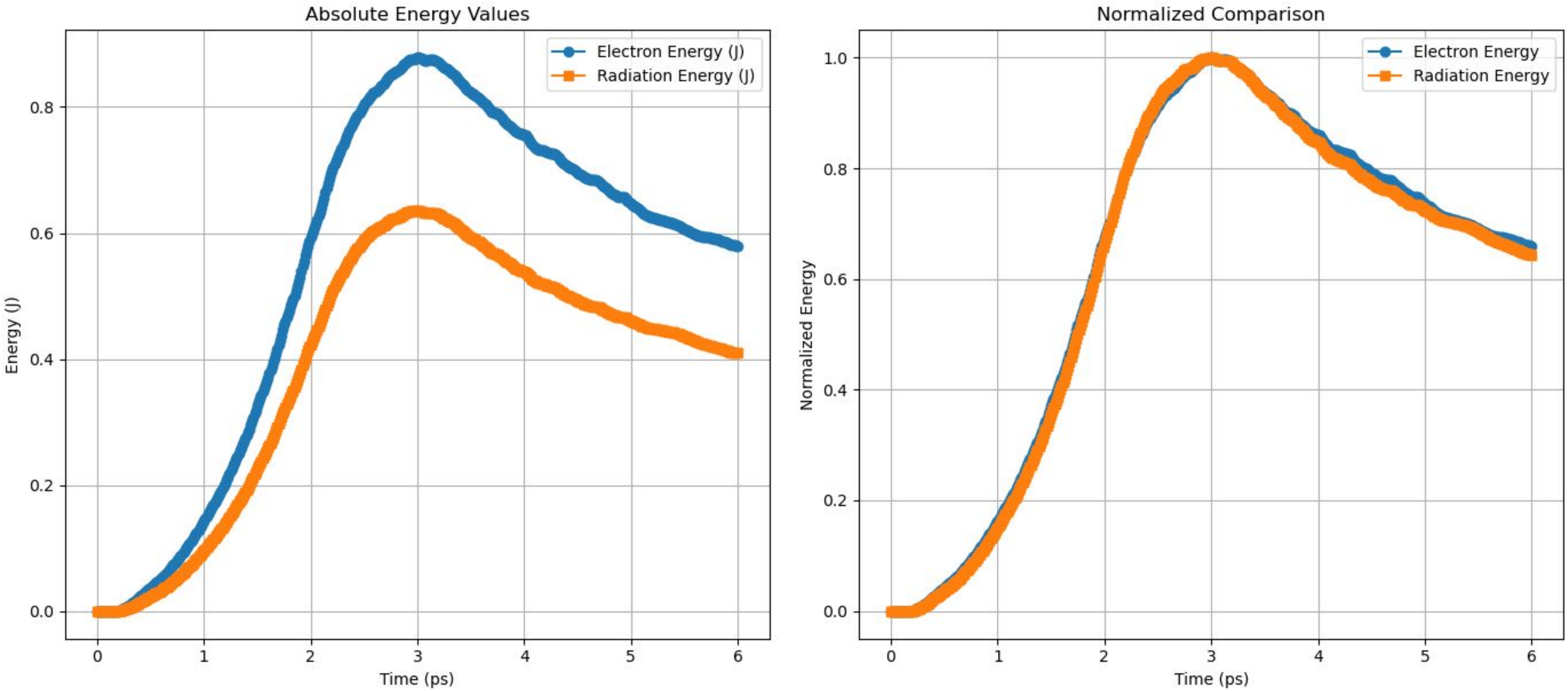
- Photon energy: **1 cm; 8% of laser energy.**
- Neutron number: **4.1 cm; 1.5e8.**

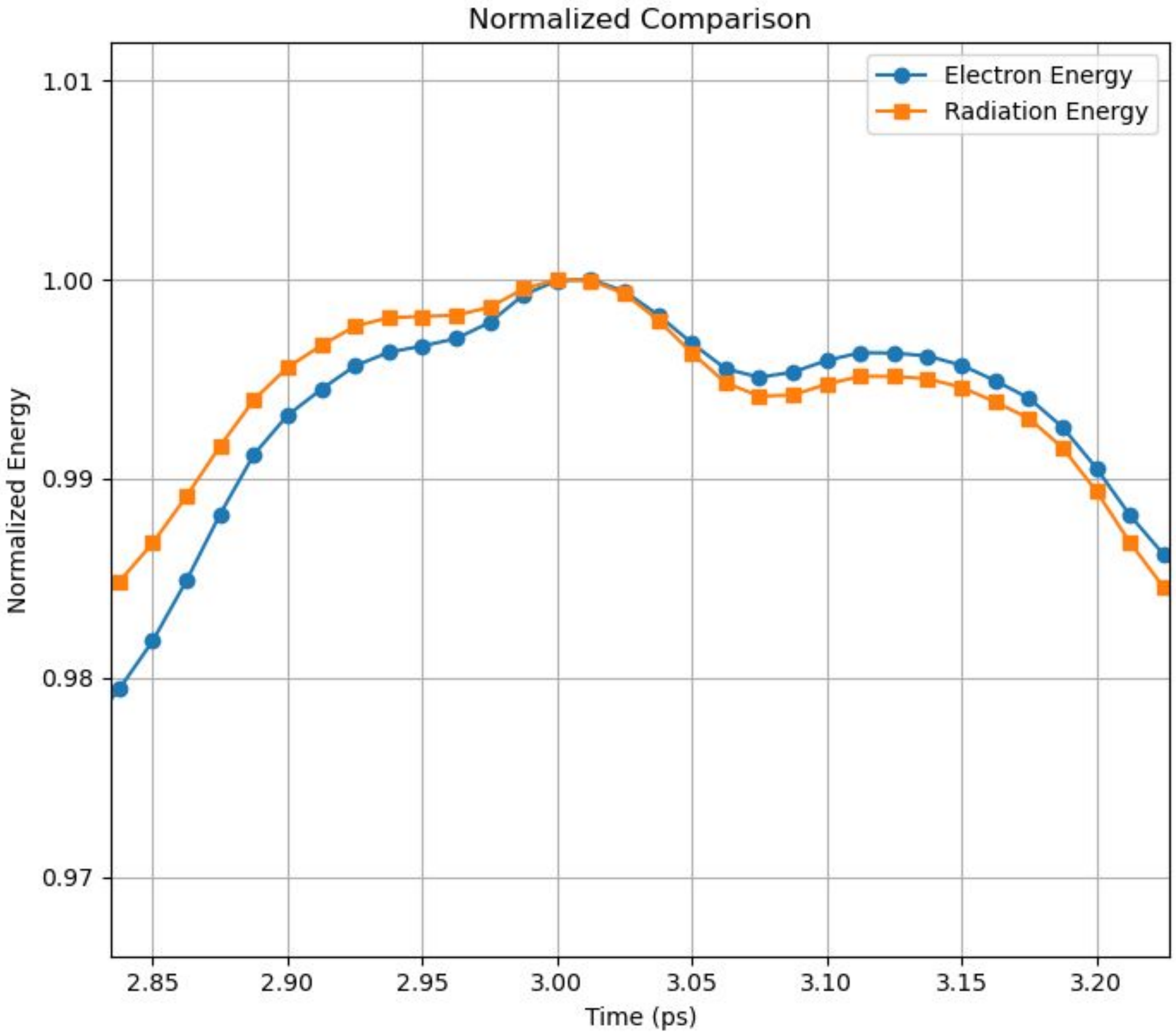
Promising to application considering:

- modest laser pulse energy (1.5 J)
- high laser to electron energy conversion (59%)
- high electron to bremsstrahlung radiation energy conversion efficiency
- high repetition electron source (1Hz)

Questions?


100 MeV Electron Energy Degradation in Lead
Remaining Electron Energy (MeV)
Cumulative Radiative Energy Loss (MeV)
Energy (MeV)
Penetration Depth in Lead (cm)
0
20
40
60
80
100
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


Absolute Energy Values
Electron Energy (J)
Radiation Energy (J)
0.0
0.2
0.4
0.6
0.8
Energy (J)
0
1
2
3
4
5
6
Time (ps)
Normalized Comparison
Electron Energy
Radiation Energy
0.0
0.2
0.4
0.6
0.8
1.0
Normalized Energy
0
1
2
3
4
5
6
Time (ps)


Normalized Comparison
Electron Energy
Radiation Energy
1.01
1.00
0.99
0.98
0.97
Normalized Energy
2.85
2.90
2.95
3.00
3.05
3.10
3.15
3.20
Time (ps)